



Jet Propulsion Laboratory  
California Institute of Technology

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# Antimonide Barrier Infrared Detector Focal Plane Arrays for Earth Science Applications

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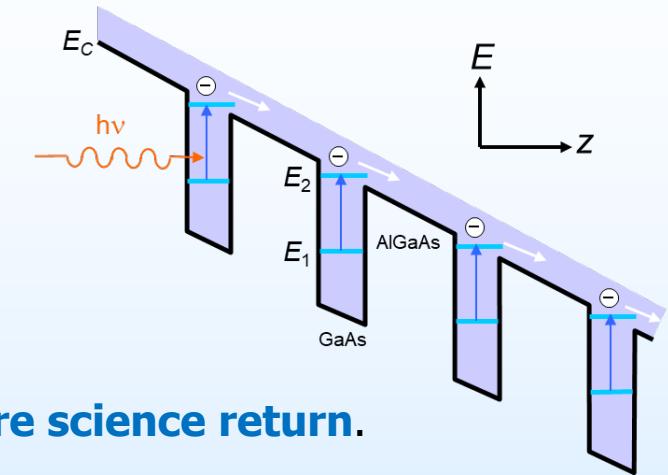
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*L3 Cincinnati Electronics*

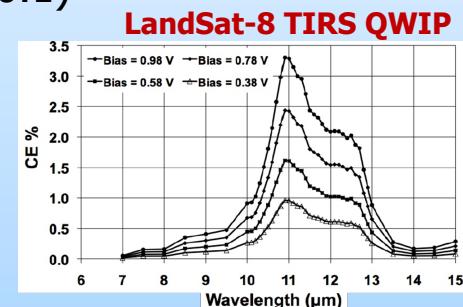
**Program:** SLI-T 15

# Motivation

- NASA successfully deployed long-wavelength **QWIP** (quantum well infrared photodetector) FPAs
  - LandSat-8 TIRS (Thermal Infrared Sensor) – Multispectral IR Imager
  - HyTES (Hyperspectral Thermal Emission Spectrometer) – Hyperspectral IR Imager
    - <https://hytes.jpl.nasa.gov/>
- QWIP FPA advantages
  - Made from **robust III-V semiconductors**, providing FPA **"-ility" advantages**
    - High operability, large-format capability, producibility, temporal stability, spatial uniformity, affordability
  - **Temporal stability** (low 1/f noise). No need for frequent system recalibration - **More science return.**
- QWIP FPA challenges
  - **Higher dark current** due to larger generation-recombination (G-R) rate; photoconductor architecture
  - **Low conversion QE**. No intrinsic normal-incidence absorption; sub-unity photoconductive gain ( $\sim 0.1$ )
  - Requires **more cooling** to control thermal dark current to achieve needed sensitivity
  - Low operating temperature: TIRS  $\sim 43$  K; HyTES  $\sim 40$  K (both with  $\sim 12 \mu\text{m}$  response)



Can we achieve higher operating temperature to reduced cooler demand for lower size, weight, and power (SWaP), and still retain the FPA 'ility' advantages ?

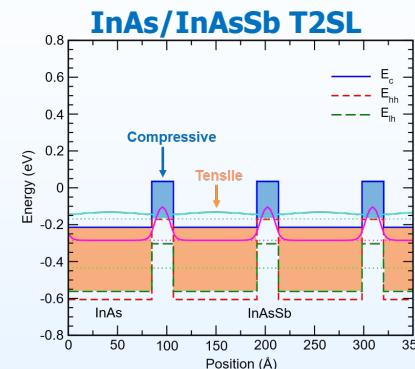
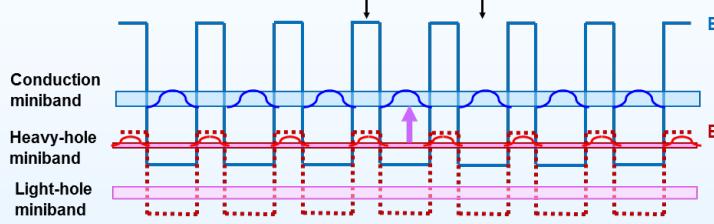


Proc. SPIE 8012 80120Q (2011).

# Advances in III-V Semiconductor IR Photodetectors

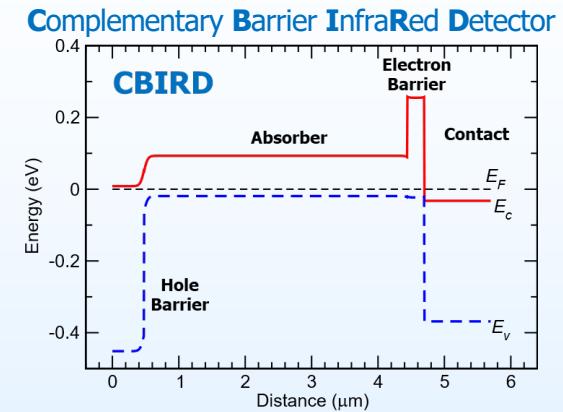
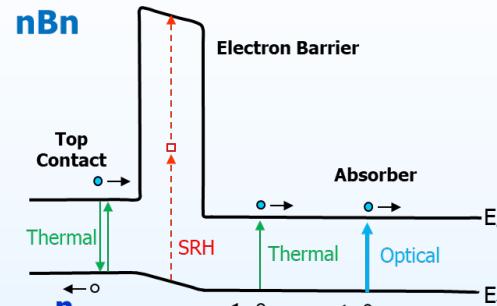
## Antimonide infrared absorbers

InAs/GaSb Type-II superlattice



- InGaAsSb alloy: 2 - 4  $\mu\text{m}$  cutoff wavelength
- Type-II superlattices (artificial IR material)
  - Continuously adjustable bandgap provides cutoff wavelength coverage from 2  $\mu\text{m}$  to >15  $\mu\text{m}$
  - Tunneling and Auger dark current suppression
- All can be grown on GaSb substrates
  - 2", 3", 4" diameter format commercially available.

## Unipolar barrier detector architecture



- Unipolar barrier detector architecture
  - Unipolar Barriers block electrons but not holes (or vice versa)
  - Examples: nBn, XBn, XBp, CBIRD
- Can suppress G-R and surface leakage dark current, w/o impeding photocurrent
- Higher operating temperature / sensitivity

The confluence of these two developments has led to a new generation of versatile, cost-effective, high-performance infrared detectors and focal plane arrays based on robust III-V semiconductors.

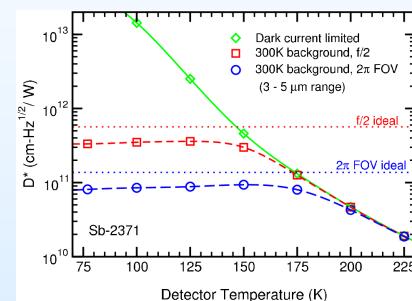
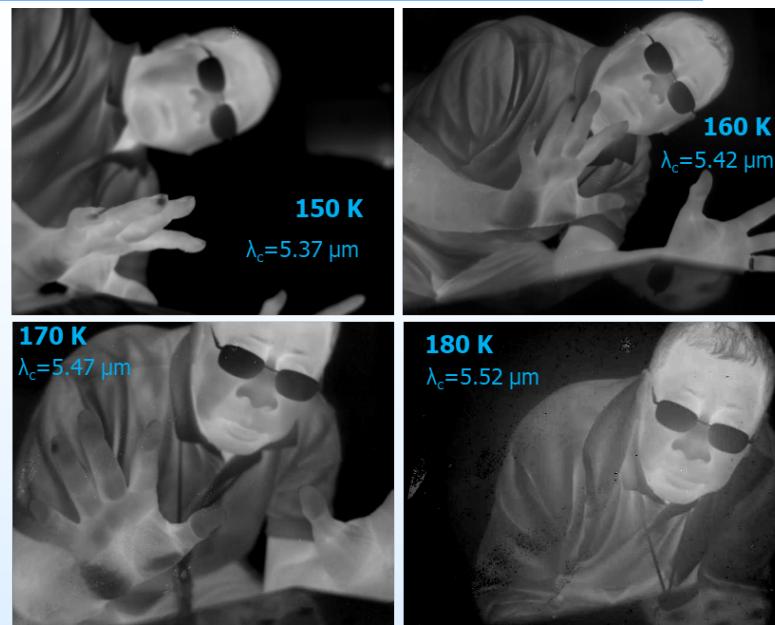
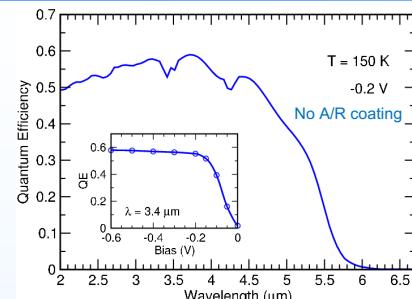
# JPL Type-II Superlattice Barrier IR Detector (T2SL-BIRD)

- Antimonide T2SL high operating temperature barrier infrared detector (**HOT-BIRD**)

- Customized cutoff wavelength to match InSb
  - Excellent FPA imaging performance at 160K
  - Comparison with InSb FPA

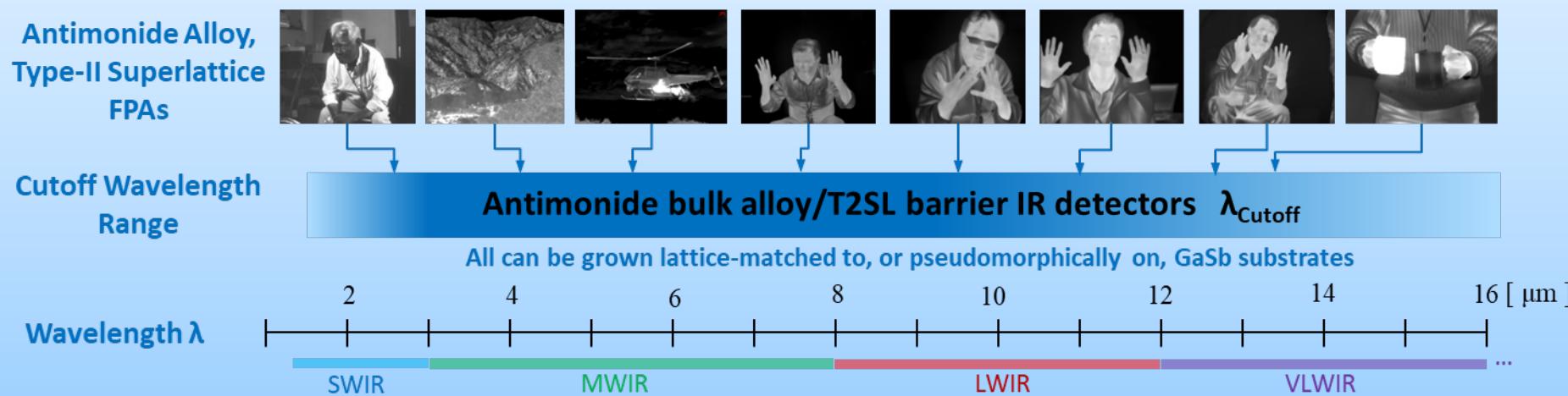
- Planar InSb (ion implant) ~ 80K. MBE epi InSb ~ 95-100K (can image up to 110-120K). **HOT-BIRD FPA operates at much higher T**.
    - InSb FPA is a major incumbent technology; leads all photodetector FPA market in volume, with >50% market share (units sold) in 2018.

- Low dark-current MWIR FPA for spectral imaging
  - For NASA CubeSat Infrared Atmospheric Sounder (CIRAS)
  - Achieved low dark current of  $J_{\text{dark}}(111 \text{ K}) = 1.8 \times 10^{-8} \text{ A/cm}^2$  required for spectral imaging application



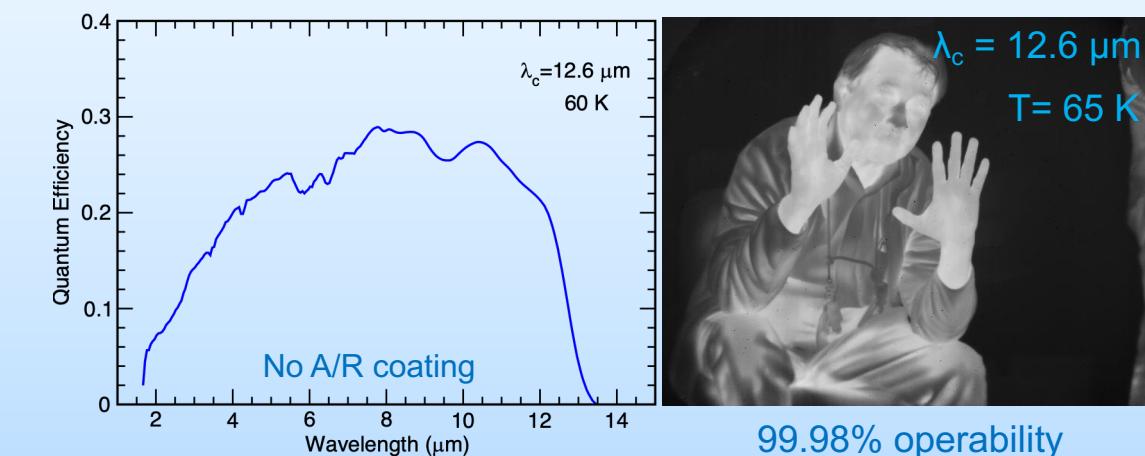
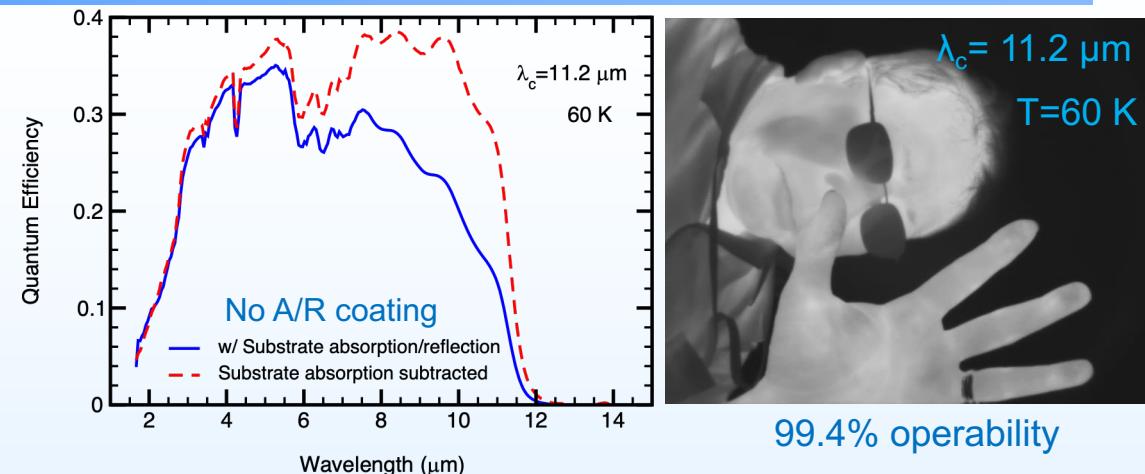
*Appl. Phys. Lett.* 113, 021101 (2018); *IEEE Photonics Journal* 10(6), 6804106 (2018).

**JPL antimonide alloy and superlattice BIRD FPA demonstrated high uniformity & operability, with cutoff wavelengths covering SWIR to VLWIR.**



# (Very) Long Wavelength Infrared FPA for Land Imaging

- Developing type-II superlattice (T2SL) barrier infrared detector (BIRD) FPAs to meet NASA Sustainable Land Imaging (SLI) interests in thermal IR bands in the 8 – 12  $\mu\text{m}$  range.
- Initial Round FPA:  $\lambda_{\text{cutoff}} \sim 11 \mu\text{m}$ 
  - SBF-193 ROIC, 640x512, 24  $\mu\text{m}$  pitch
  - FPA with  $\lambda_{\text{cutoff}} \sim 11.2 \mu\text{m}$  T2SL absorber material
  - $J_{\text{dark}}(60\text{K}) \sim 7 \times 10^{-5} \text{ A/cm}^2$ ; QE  $\sim 37\%$ , no A/R coating.
  - FPA operability  $\sim 99.4\%$
- Second Round FPA:  $\lambda_{\text{cutoff}} > 12 \mu\text{m}$ 
  - Longer cutoff; improved dark current; SBF-193 ROIC
  - FPA with  $\lambda_{\text{cutoff}} \sim 12.6 \mu\text{m}$  T2SL absorber material
  - $J_{\text{dark}}(65\text{K}) \sim 3 \times 10^{-5} \text{ A/cm}^2$ ; QE  $\sim 27\%$ , no A/R coating.
  - FPA operability  $\sim 99.98\%$
  - Estimated 20K operating temperature advantage over QWIP FPA. Reduce cooling demand for favorable SWaP.

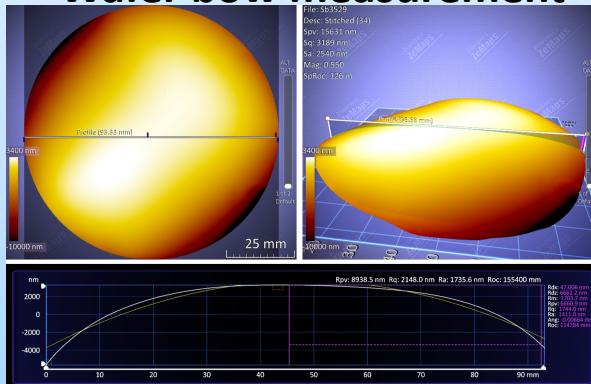


Long wavelength type-II superlattice (T2SL) barrier infrared detector (BIRD) FPAs can provide an estimated 20 K operating temperature advantage over existing QWIP FPAs.

# Long-wavelength T2SL BIRD for “Silicon Sandwich” FPA

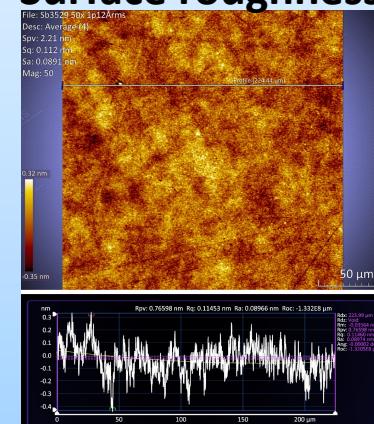
- L3 Cincinnati Electronics patented “silicon sandwich” process favorable for large-format FPA
- JPL/L3 collaboration to implement long-wavelength T2SL barrier IR detector silicon-sandwich FPA
- Detector material wafers designed, grown, and characterized at JPL
  - L3 process requires bonding III-V semiconductor wafer to silicon wafer first (transfer detector layer to silicon wafer)
  - Stringent wafer-bow requirements for the detector wafer
  - Material/wafer characterization: very good X-ray diffraction, surface roughness, wafer bow
  - Four 4-inch diameter wafers sent to L-3 for FPA fabrication
- A sister wafer used for detector fabrication/characterization at JPL
  - Demonstrated good LWIR detector characteristics
  - At 60 K,  $\lambda_{\text{cutoff}} = 11.6 \mu\text{m}$ ; QE  $\sim 30\%$  at  $8.6 \mu\text{m}$  (no A/R coating); dark current density  $\sim 6 \times 10^{-6} \text{ A/cm}^2$

Wafer bow measurement



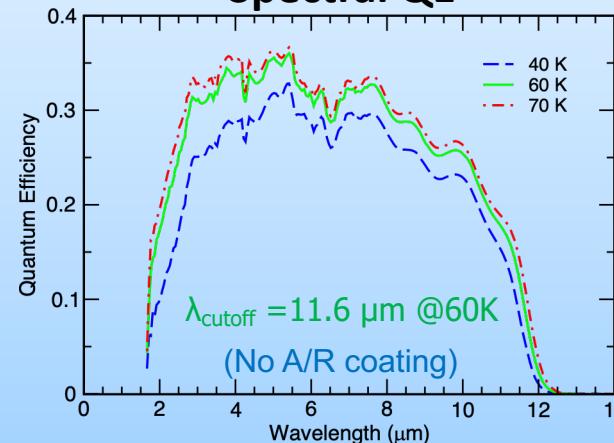
Peak to valley= 15.6  $\mu\text{m}$   
(4-inch diameter wafer)

Surface roughness

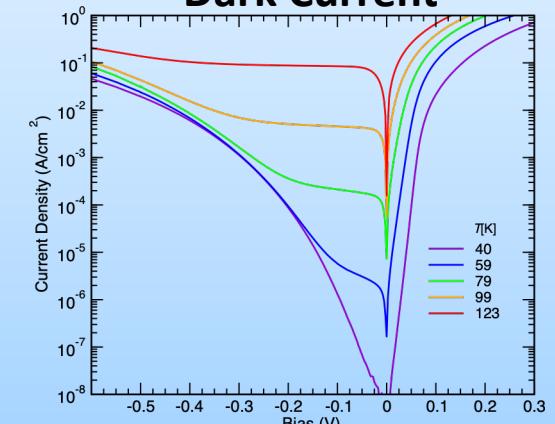


RMS roughness= 1.12 Å

Spectral QE



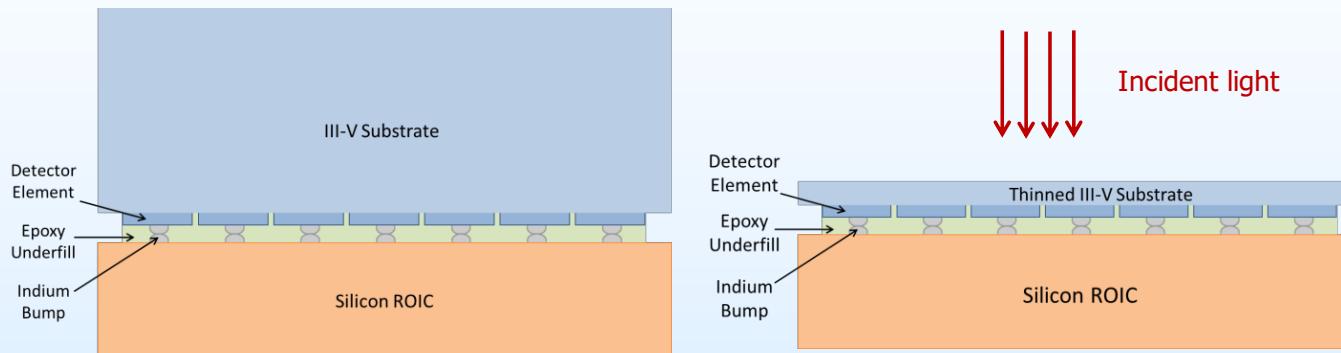
Dark Current



# LW T2SL BIRD “Silicon Sandwich” FPA Demonstration

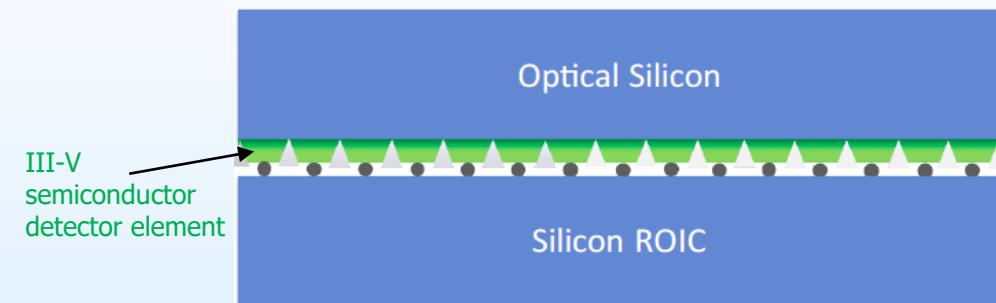
## Conventional FPA

- Fabricate detector arrays on III-V semiconductor detector wafer
- Hybridize detector array to silicon ROIC
- Remove III-V substrate to avoid thermal mismatch with silicon ROIC

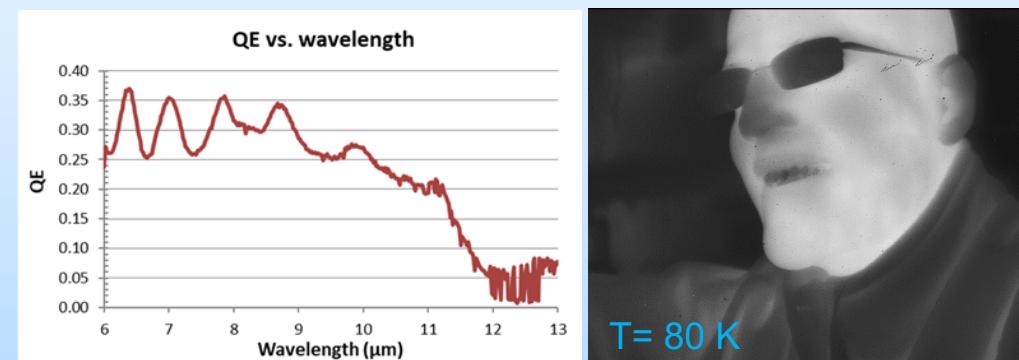


## L3 “Silicon Sandwich” FPA

- III-V detector wafer bonded to silicon wafer
- Remove III-V substrate (leaving detector layer on silicon)
- Fabricate detector arrays on silicon wafer
- Hybridize detector array to silicon ROIC.



- Successfully demonstrated “Silicon Sandwich” FPA with LW T2SL BIRD
  - L3 fabricated FPAs using FLIR ISC-1308 ROIC (1280×1024, 12 μm pitch)
  - Dark current density:  $J_{\text{dark}}(69.4\text{K}) = 1.9 \times 10^{-5} \text{ A/cm}^2$ ; QE=29% (8-10 μm)
  - NEDT = 29.2 mK at 69.4K (27.5 °C background, F/2 optics, 7.7-10 μm filter)
  - Operability: 99.5%
- An integrated dewar cooler assembly (IDCA) is being built at L3



**The successful demonstration of silicon sandwich FPA paves the way to multi-megapixel long-wavelength T2SL BIRD FPAs for high-resolution applications.**

# References /Acknowledgement

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